The Use of Audio in Minimal Access Surgery

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Abstract

In minimal access surgery (MAS) (also known as *minimally invasive surgery*), operations are carried out by making small incisions in the skin and inserting special apparatus into potential body cavities through those incisions. Laparoscopic MAS procedures are conducted in the patient's abdomen. The aim of MAS is faster recovery, shorter hospitalisation and fewer major post-operative complications; all resulting in lower societal cost with better patient acceptability. The technique is markedly dependent on supporting technologies for vision, instrumentation, energy delivery, anaesthesia, and monitoring. However, in practice, much MAS continues to take longer and be associated with an undesirable frequency of unwanted minor (or occasionally major) mishaps. Many of these difficulties result precisely from the complexity and mal-adaptation of the additional technology and from lack of familiarity with it. A survey of South East England surgeons showed the two main stress factors on surgeons to be the technical difficulty of the procedure and time pressures placed on the surgeon by third parties.

Many of the problems associated with MAS operations are linked to the control and monitoring of the equipment. This paper describes work begun to explore ergonomic enhancements to laparoscopic operating technology that could result in faster and safer laparoscopic operations, less surgeon stress and reduce dependence on ancillary staff.

Auditory displays have been used to communicate complex information to users in a modality that is complementary to the visual channel. This paper proposes the development of a control and feedback system that will make use of auditory displays to improve the amount of information that can be communicated to the surgeon and his assistant without overloading the visual channel. Control of the system would be enhanced by the addition of voice input to allow the surgeon direct control.

Keywords Auditory Display, Minimal Access Surgery, Minimally Invasive Surgery

Introduction

In minimal access surgery (MAS) (also known as *minimally invasive surgery*) operations are carried out by making small incisions in the skin and inserting special apparatus into potential body cavities held patent (usually) by CO_2 gas through those incisions. Laparoscopic MAS procedures are conducted in the patient's abdomen. A typical laparoscopic procedure will require the surgeon to have continuous control and monitoring of a number of devices.

Although MAS results in a number of favourable outcomes for the patient (such as lower wound-associated morbidity and shorter post-operative recovery) the procedures can take longer than conventional methods. There are also problems associated with the technique and the associated equipment that make MAS stressful and more difficult for the surgical team.

This paper outlines some of the problems faced in MAS operations and proposes a command/control system for laparoscopic equipment that makes use of the audio channel for communicating information to the surgeon.

Control in Laparoscopic MAS

A typical laparoscopic procedure requires a number of devices to be used, namely:

- Surgical instruments for carrying out the operation itself. These are indirectly worked by hand-operated controllers outside the patient's body.
  Video camera (endoscope). The endoscope provides pictures of the body cavity.
- Video monitor (VDU). The signals from the endoscope are displayed on the VDU.
- Light box. The light box provides illumination of the workspace for the endoscope.
- Insufflator. This machine is for inflating the body cavity with CO_2 gas. It is designed to deliver the gas at a desired flow rate, and to measure the absolute pressure generated within the body cavity being filled.
- Diathermy unit (electronic cautery).
- Video cassette recorder (VCR). Procedures may be recorded onto videotape for future reference/teaching.
- Anaesthetic machine/monitor (the major piece of machinery used by the anaesthetist in anaesthetising and monitoring the patient).

The surgical instruments and the diathermy unit are controlled directly by the surgeon (the diathermy by means of a foot-operated latched switch). The endoscope requires a surgical assistant for positioning and ensuring optimal views of the operative site. Control of the remaining devices requires manipulation of front-panel controls. As both of the surgeon's hands (and one foot) are needed for manipulating the surgical instruments, operation of the electronic devices requires third-party intervention by the assistants or auxiliary theatre staff.

As the surgeon orientates the instruments within the patient, he must occasionally adjust his position accordingly. Consequently, the VDU may need repositioning; the operation must stop until this is carried out, with the all the disadvantages this imposes.

Throughout the operation, the flow of CO_2 from the insufflator needs to be regulated. If the CO_2 pressure drops below the pre-set level required to hold patent the potential body cavity, then extra flow is needed to reinflate the body cavity; this requires direct manipulation of the insufflator by theatre staff instructed by the surgeon. An added problem is that loss of pressure often occurs slowly (e.g. via a slow leak in the skin incision), the surgeon only realising the problem once the operation is impeded, whether due to a loss of vision or a loss of space disallowing instrument manipulation. Thus, all work must stop until pressure is restored.

The camera must be moved and the picture adjusted (zoom, pan and orientation) by a surgical assistant under instruction from the surgeon. In addition, depending on lighting conditions, the output of the light box will need adjusting, as may the VDU image.

Monitoring

Throughout the operation, the surgeon and his team must monitor the equipment to gain information about the procedure and the patient's state. The information the surgeon receives regarding the status of the equipment and the patient's state will influence the direction of the procedure and the control decisions that the surgeon and his team will make. The VDU is monitored visually and is the primary source of information regarding the operation for the surgeon and his assistant(s). Important patient physiology data is imparted to the surgeon by the anaesthetist. This is given either, on demand, or voluntarily by the anaesthetist if a problem arises that requires the operation to cease, usually temporarily, until the problem is rectified.

All other equipment is monitored by the surgeon visually and aurally. Visual monitoring requires the surgeon to change his focus from the VDU to the readouts and gauges of the various devices. Aural monitoring is accomplished in two ways:

- By the asking others to tell him what he wants to know. This is an indirect information flow.
- By listening to the running noises of the devices to ascertain their state (much as one listens to a car engine while driving). Some devices will also give auditory alarms of exceptional events. This is a direct information flow.

Patient state data can be categorised as *anatomical* and *physiological*. Anatomical information (e.g. the state of an organ, the position of blood vessels, etc.) is largely gathered visually by inspecting the operative space. Much of this information can be gained by looking at the VDU, although image processing and enhancement techniques may be able to reveal hidden features (such as tissue density). Physiological information includes variables such as body temperature, blood pressure, heart rate, and blood CO_2 saturation. The anaesthetist is responsible for measuring such factors to ensure that the patient remains in a stable-enough state to allow the operation to proceed safely. However, the surgeon needs to be aware of unexpected changes in the values of these variables. The procedure itself may adversely affect the patient. For example, inflation of the body cavity "splints" the diaphragm, and this can cause problems with respiration making it necessary to vent the body cavity of the gas. Conversely, adverse patient physiology will require the operation to be halted until the patient is stabilised. The surgeon is dependent on the anaesthetist for such information.

If such physiological data could be provided to the surgeon continuously, then it might be possible to avoid situations that require remedial action, thus shortening the operation and reducing patient recovery time.

Problems with Laparoscopic MAS

The nature of laparoscopic MAS means that all the feedback from the surgical instruments is indirect. In conventional open surgery the surgeon can see and feel the tissues he is working with up close. This means he has good information about the size and densities of the tissue. The surgeon also gains information from the resistance the tissues give. However, in MAS the instruments used mean that very poor tactile (haptic) feedback is attained (Stassen et al., 1997). This leads to problems of control and co-ordination (Breedveld, 1997).

The visual feedback available is very limited. To monitor any of the devices himself, the surgeon must change his focus from the VDU to the device in question, creating an interruption in the procedure and a possible loss of context, both of which have associated recovery times (and concomitant cost implications).

Visual monitoring of anything other than the VDU requires a change of visual focus. The surgeon's visual channel runs close to (if not already at) capacity with the need to look continuously at the video monitor. The operation takes place in three-dimensional (3D) space within the patient. However, the VDU only provides a two-dimensional (2D) mapping of the events. With practice, surgeons are able to mentally create a pseudo-3D representation from the 2D image, but this has to be reconstructed each time focus is shifted away from the VDU. Anything that requires the surgeon to divert his attention from the monitor means that time is lost in reacquiring the link between the 2D image and the 3D workspace. This results in additional strain being placed on the surgeon.

In addition to the ergonomic problems of working in this way, the surgeon is completely dependent on the technology for accurate visualisations of the operative field.

The requirement to have a qualified assistant (usually a junior member of the surgical team) to operate the endoscope accounts for a significant proportion of operating costs. The addition of the auxiliary personnel needed to monitor and control the equipment on the videolaparoscopy trolley also increases costs. Furthermore, the number of people involved increases the number of possible communication channels and the scope for misunderstandings and confusion. This requires additional training for the assistant and the auxiliary staff and can lead to delays in the procedures, which again add to costs.

The problems identified above contribute to an increase in psychological and physical strain on the surgeon. A recent survey of surgeons in South East England identified the two main stress factors on surgeons to be the technical difficulty of the operation and the time pressures imposed on the surgeon. Increasing the psychological and physical stresses leads to an increase in the time it takes surgeons to recover from carrying out operations. This has an impact on surgeon productivity.

The above problems also serve to increase the time taken to carry out MAS procedures. Increased procedure time multiplies the associated patient-related problems such as increased morbidity from the anaesthetic and longer post-operative recovery times.

The net result of these factors is an increase in cost. Costs may be measured simply and directly in the monetary value of staff time, resources used and cost of accommodating patients. They may also be measured in terms of their societal impact in terms of workdays lost to sickness and stresses placed on the families of patients.

Data Sources and Information Requirements

Information flows two ways in a laparoscopic MAS procedure. The surgeon controls the procedure by sending control messages to the system components (the theatre equipment and staff). A typical endoscopic operation requires twenty to thirty functions to be controlled (Fiennes, 1996). Apart from the manipulation of the surgical instruments and the diathermy unit over which the surgeon has direct control, all other functions must be executed by intermediaries.

The surgeon receives information from four principal sources (Fiennes, 1996):

1. The VDU (via the endoscope) presents an *indirect* real-time patient image.
2. The anaesthetic monitor provides data on patient physiology, though this is relayed to the surgeon via the anaesthetist, and then only on demand or when a problem arises.
3. The laparoscopic equipment (endoscope, surgical instruments, light box, insufflator, diathermy, VDU, & VCR) provides status signals (both aurally and visually).
4. Pre-operative imaging (X-rays, scans etc.) and procedure plans provide additional data.

Control messages pass from the surgeon to the system components, and status data flow from the system to the surgeon. The equipment in a modern endoscopic operating theatre typically comprises during an operation (Fiennes, 1996). Presently, much of this control requires human intermediaries in the form of surgical assistants and auxiliary staff.

Statement of Need

To help overcome some of the problems associated with MAS, the surgeon should be able to maintain direct control of the laparoscopic equipment without breaching the sterile barrier and without interrupting the complex eye, hand, and foot tasks of surgery (Fiennes, 1996).

Second, the surgeon needs a system that will provide the information he requires with minimum reliance on intermediaries. Patient physiological anatomical data should be readily available. Information about equipment status should be easily obtained and in an easy-to-use form.

Possible Solutions

The control aspects may be addressed in a number of ways (Fiennes, 1996):

1. Each function could have its own input channel (e.g. a toggle or latch switch). Although this gives an advantage that each control would have an unambiguous response, delays in sending the command or operation of the wrong switch could have severe consequences. The ergonomic aspects of such a control interface would be problematic, as would the need to preserve the sterile barrier.
2. Functions could be arranged into subgroups and the number of unique controls reduced accordingly. This is done commonly in the everyday world (e.g. multi-function buttons on electronic apparatus) but increases the problem of interface design and increases the complexity of the instructions needed to carry out the tasks. If implemented well, such interfaces can be very successful, but poor designs lead to increased stress and possibility of error. Examples of poor multi-function designs can be found on most consumer electronic equipment such as VCRs and telephones. See Norman (1988) for a good discussion of many of the issues involved.
3. A complete system interface could be constructed that would allow control of all equipment functions. Common design principles would apply throughout.

If such a control interface were to be built, the question arises as to the input modalities to be used. Keyboards, mice, pedals and stylus-and-tablet systems would be relatively simple to construct but would require the surgeon to let go of the surgical instruments in order to control the devices. This is unsatisfactory as it interrupts the flow of the operation.

An alternative solution would be to use a speech-recognition system to allow the surgeon to give vocal commands to the system. Prototype systems to control MAS equipment have already been developed and demonstrated (e.g. AESOP (Sackier et al., 1997), and voice-activated insufflators (Besant et al., 1992,Olama et al., 1996)).

To provide information about system and patient state it is usually proposed that techniques to display the information on the VDU be used. Indeed, the VDU could, with care, be enhanced to include readouts of the necessary data. However, there are many ergonomic issues to address with this strategy. First, even data on the VDU would require the surgeon's visual focus to shift from the main display. Secondly, it may not be possible to put all required information on the screen at the same time which introduces further problems of control and the surgeon not having the information available when needed.

Auditory Display and MAS

A feature of the visual system is that it is hard to attend to more than one visual stream at once. This becomes even more difficult in laparoscopic procedures where a very high level of visual concentration is required to monitor the VDU display of the operative area. So far, with the exception of simple auditory warnings, the role of sound as an information display modality has been largely ignored. Sound offers the potential for delivery of multiple data streams in parallel as the human auditory system is not restricted to single-channel attention (Yost, 1994). Listeners of music are able to pick out different instruments even though the sound comes from a single source (a loud speaker).

In recent years, efforts have been made to find ways of using sound to communicate complex data and information. The practice of using sound to present information has been termed *auditory display* (Kramer, 1994). At its simplest, an auditory display can be an audio alarm that signals some exceptional event or data value. A fire alarm is a good example of this. In this case, it is obvious that an auditory signal is preferable to a visual display: to be aware of information displayed visually, one must be attending to the visual display source at the time the event occurs. With sound, one's attention need not be continuously given to the source.

However, sound offers much more than the mere ability to give simple warnings. Auditory displays have been successfully constructed to communicate information about:

- Stock market prices (Kramer, 1994).
- Chemical compound spectra (Lunney and Morrison, 1981,Lunney et al., 1983,Lunney and Morrison, 1990).
- Seismic data (Hayward, 1994).
- DNA nucleotide sequences (King and Angus, 1996).
- Program and algorithm state and behaviour (Jameson, 1994,Vickers and Alty, 1996,Alty and Vickers, 1997,Alty et al., 1997,Vickers and Alty, 1998).
- Diagram readers for the blind (Rigas, 1996,Rigas and Alty, 1997,Alty and Rigas, 1998).

Of particular interest in the context of laparoscopic MAS are the auditory mappings of physiological data created by Fitch and Kramer (1994). In this piece of work, the physiological variables heart-rate (BPM), body temperature (°C), blood pressure (mmHg), blood CO_2 level (mmol/L), respiratory rate (breaths-per-minute), atrio-ventricular dissociation (present or absent), fibrillation (present or absent), and pupillary reflex (present or absent) were mapped to different parameters of two auditory streams: the heart signal and the breathing signal. The heart signal was represented by a low-pitched repetitive thudding noise. Two pitches were used to represent the atrial and ventricular contractions. The breathing signal was achieved by amplitude-modulating noise in time with the breathing rate. The remaining variables modulated different aspects of these two base audio streams (Fitch and Kramer, 1994). For example, blood pressure controlled the pitch of the heart sound and CO_2 level modified the timbre (brightness) of the sound. An experiment showed that subjects could readily learning to use the auditory display in less than an hour. The subjects were able to identify changes in patient state from the display and recommend the appropriate response (e.g. introducing digitalis when the heart rate increased).

A properly constructed auditory display, taking into account ergonomic, environmental, and cognitive constraints, could provide the surgeon with access to much of the information he requires without the intervention of intermediaries.

Proposed System

We have begun a research project whose to construct a control and display system for laparoscopic MAS equipment. Figure 1 shows a top-level design for such a system with the surgeon providing voice (or even haptic) input to control the devices. A separate until will generate auditory displays (where appropriate) of the various data streams.

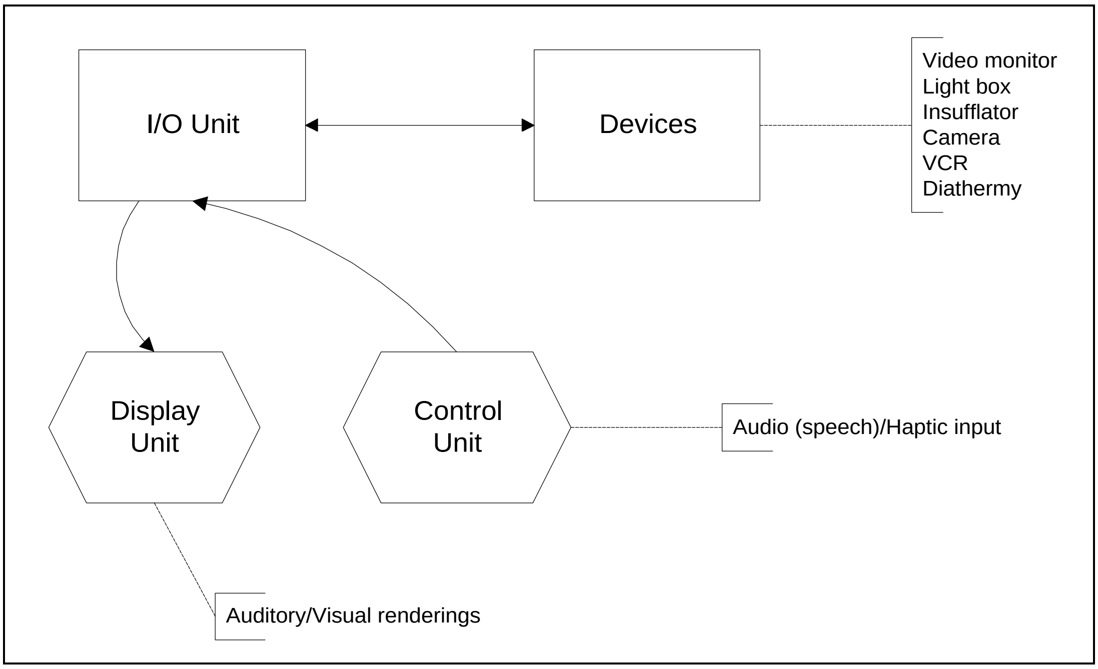

Figure 1 MAS Control & Display Unit

A full investigation of the acoustic environment in an operating theatre must be conducted to ensure that the audio signals are compatible. Any auditory displays would also need to be compared with corresponding visual displays to ensure their efficacy.

The hypothesised benefits (to be assessed by empirical evaluation) of such a system are:

1. Gains in task performance speed and quality
2. Reduced stress
3. Releasing of auxiliary personnel for other tasks
4. A consequent reduction in cost (monetary and societal) of MAS.

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